

Lychee Quality After Hot-water Immersion and X-ray Irradiation Quarantine Treatments

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Abstract. Hot-water immersion and irradiation quarantine treatments are used to disinfect lychee (*Litchi chinensis* Sonn.) of fruit flies and other pests before export from Hawaii to the U.S. mainland. In the first experiment, one day after harvest, 'Kaimana' lychee fruit were subjected to 1) hot-water immersion at 49.0 °C for 20 minutes, 2) irradiation treatment at a minimum absorbed dose of 400 Gy, or 3) left untreated as controls. Fruit were then stored at 2 or 5 °C in perforated plastic bags, and quality attributes were evaluated after 8 days. Lychee fruit treated with hot-water immersion were darker (lower lightness) and less intensely colored (lower chroma) than irradiated or untreated fruits at both storage temperatures. Fruit stored at 2 °C were darker (lower lightness) than fruit stored at 5 °C, but fruit held at 5 °C had greater weight loss. External appearance of fruit treated with hot-water immersion was rated as unacceptable, whereas irradiated and nontreated fruit were rated as acceptable. Taste of fruit was rated as acceptable in all treatments. In the second experiment, lychee fruit were subjected to 1) hot-water immersion at 48, 48.5, or 49 °C for 20 minutes or 2) irradiation at 400 Gy, or 3) left untreated as controls. Fruit were then stored at 4 °C in perforated plastic bags, and external appearance of the pericarp was evaluated after 1, 2, 5, 7, 8, and 9 days. Pericarp darkening was more rapid for lychee fruit treated with hot-water immersion than irradiated or control fruit, and the degree of quality loss increased with increasing hot-water immersion temperature. Overall, under these experimental conditions, irradiation was superior to hot-water immersion as a quarantine treatment on the basis of fruit quality maintenance.

Lychee (*Litchi chinensis* Sonn.) (syn. litchi, litchee, leechie, lin-chi, laici, li-chi, and tu hu), a subtropical evergreen tree fruit in the family Sapindaceae, is indigenous to South China (Morton, 1987; Nakasone and Paull, 1998). Lychee is a nonclimacteric fruit with a red pericarp and a milky white edible aril (the "skin" and "flesh," respectively) surrounding a single seed (Paull and Chen, 1987). In Hawaii, lychee is one of the main crops of the rapidly expanding tropical specialty fruit industry, and there is substantial commercial interest in exporting fresh lychee to the U.S.

mainland. 'Kaimana', 'Kwai Mi', and 'Groff' are the major cultivars.

Lychee, like many other tropical fruits grown in Hawaii, is under a federal quarantine because the fruit is a potential host of the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann), and the oriental fruit fly, *Bactrocera dorsalis* Hendel. These pests are not established in the continental United States, and commodity quarantine treatments ensure that the risk of exporting them from Hawaii is minimized (Follett and Sanxter, 2000). A major problem in marketing lychee is rapid pericarp browning, which makes them unattractive although the aril remains edible. Much of the postharvest research has been directed at prevention of pericarp browning (e.g., Jacobi et al., 1993; Paull and Chen, 1987; Paull et al., 1995; Underhill and Critchley, 1993).

Two quarantine treatments have been developed for exporting lychee from Hawaii to the U.S. mainland. Irradiation with a minimum absorbed dose of 250 Gy is an approved treatment by the U.S. Dept. of Agriculture, Animal Plant Health Inspection Service (USDA-APHIS) for disinfestation of fruit flies in lychee (Federal Register, 1998). Since 1995, various tropical fruits, including lychee, have been flown from Hawaii to the U.S. mainland for irradiation treatment and subsequent distribution and sale. This practice is expensive because of the limited number of treatment facilities and their distances from major markets. An e-beam/converted X-ray facility has recently been constructed in Ha-

waii, and other irradiation facilities may be forthcoming if market interests grow. Irradiation with a minimum absorbed dose of 400 Gy is accepted by the California Dept. of Food and Agriculture (CDFA) for the treatment of insects other than fruit flies (Follett and Lower, 2000). The commercial irradiation facility in Hawaii typically treats all tropical exotic fruits at this level to avoid rejections due to the presence of non-fruit fly quarantine pests. A hot-water immersion treatment of 49.0 °C for 20 min, is another USDA-APHIS-approved treatment for lychee from Hawaii (Federal Register, 1997). Hawaii has one hot-water immersion treatment facility that has recently been certified (Follett, 2002). The purpose of this study was to make a direct comparison of the effects of these two postharvest treatments on lychee quality during storage under simulated commercial conditions.

Materials and Methods

Lychee fruit (Kaimana cv.) were obtained from growers in Papaikou and Hilo, Hawaii, during a commercial harvest on the island of Hawaii from June through July 2001, removed from the panicles, and stored in the laboratory in perforated plastic bags in fiberboard boxes at 25 ± 1 °C. One day after harvest, undamaged fruit were randomized for treatments, and baseline quality analyses (described below) were performed on fruit samples before initiation of quarantine treatments. In the first experiment, fruit were treated that day with one of two quarantine treatments: hot-water immersion (HWI) at 49 °C or irradiation (IRR), or left untreated as controls. A factorial design consisting of three quarantine treatments (control, irradiation, hot-water immersion) × two storage temperatures (2 and 5 °C) was used. Fruit were harvested ripe from the tree on three successive weeks, and each harvest date constituted a replicate of the experiment (n = 3). In the second, separate experiment, fruit were treated on the day after harvest with one of four treatments: hot-water immersion at 48, 48.5, or 49 °C, irradiation, or left untreated as controls. Fruit for all treatments were stored at 4 °C. Fruit were harvested ripe from the tree on two successive weeks, and each harvest date constituted a replicate of the experiment (n = 2). Methods given below are specific to the first experiment; deviations from these methods for the second experiment are given at the end of each section.

Hot-water immersion treatment. Tests were conducted at the USDA Agricultural Research Service (ARS) laboratory in Hilo using a 70-L circulating bath heated by two electric heaters (PolyScience immersion circulator model 73) to a constant 49 ± 0.2 °C. This hot-water immersion tank was specifically designed for postharvest research on fresh tropical commodities (Follett and Sanxter, 2001). The bath temperature was verified before and after each run using a mercury thermometer with 0.1 °C gradations. For HWI treatment, 2.3 kg of fruit were placed in a nylon mesh bag and immersed in water at 49 °C for 20 min. After heating, the fruit were immediately placed into a 70

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L ambient (21 °C) water bath to cool for an additional 20 min. Seed surface temperatures were recorded from a sample of fruit of various sizes using thermocouples (type J) and a data logger (Polycorder model no. 516C-64-A; Omnidata International, Logan, Utah). Typical HWI temperature profiles are shown in Fig. 1. Fruit were then air-dried in shade for ≈ 1.5 h before repacking in perforated plastic bags and fiberboard boxes (36.2 \times 26.4 \times 14.9 cm) for storage at 2 or 5 °C. Seed surface temperatures of fruit stored at 2 °C cooled from 23 to 5 °C in 10 h and reached 2 °C in 16 h, whereas fruit stored at 5 °C cooled to 10 °C in 6 h and 5 °C in 13 h. In the second experiment, a series of hot-water bath temperatures between 48 and 49 °C, was used, and fruit were stored at 4 °C, but otherwise methods were as described above. Lower temperatures (48.0 and 48.5 °C) were included in this experiment because recent evidence suggested that they may be adequate to provide quarantine security against fruit flies in lychee (unpubl. data), and because 49 °C treatment appeared to damage the fruit.

Irradiation treatment. For treatment with irradiation, 4.5 kg of fruit in a perforated bag inside a fiberboard box were treated at a nearby commercial X-ray facility (Hawaii Pride, Keaau, Hawaii) using an electron linear accelerator (5 MeV, model TB-5/15; SureBeam Corp., San Diego, Calif.) at ambient temperature. Dosimeters (Opti-chromic detectors, FWT-70-83M; Far West Technology, Goleta, Calif.) were placed at six locations inside and two locations outside the box. The dosimeters were read with a FWT-200 reader (Far West Technology, Goleta, Calif.) at 600-nm absorbance to verify the minimum absorbed dose and dose variation in each replicate. About 1 h after irradiation treatment, fruit were placed in storage at 2 or 5 °C. Over the course of the study, calculated doses (dosimeters inside boxes only) ranged from an average minimum of 417 Gy to an average maximum of 560 Gy, for a dose uniformity ratio of 1.34. In the second experiment, 4.5 kg of fruit were treated as above, and 20 fruit were selected randomly from each treatment for repeated evaluation.

Quality determination. In the first experiment, fruit quality determinations were performed before treatment and after 8 d storage (9 d after harvest) at 2 or 5 °C with relative humidity at 80%. Quality evaluations included colorimeter measurements, % soluble solids content (SSC), pH, total acidity, and visual ratings of external appearance, and sensory evaluations of peel and pulp texture, and taste. Twenty-five fruit were evaluated per replicate (harvest date) on the day of fruit arrival (1 d after harvest), and 25 fruit/treatment/replicate were evaluated after 8 d storage. Quantitative measurements of the external color of the pericarp were made using a Minolta Chroma Meter (Minolta Corp., Ramsey, N.J.), calibrated to a standard white reflective plate and recording in the L^{*}C^{*}h[°] color system (lightness, chroma, and hue angle, respectively). Measurements were taken across an area 8 mm² with diffuse illumination at a viewing angle of 0° under Commission Internationale de l'Eclairage (CIE) illuminant C conditions (McGuire,

1992, 1998). Color values were recorded at four equidistant locations around the equator and one at the distal end and averaged for each fruit. The color values for each treatment were averages of 25 fruit. One color reading was taken for the pulp at the blossom end of each of the 25 fruit. Ten of the 25 fruit were used for chemical analysis. The juice of each fruit was extracted individually by pressing the pulp through a garlic press with 1-mm-diameter openings, and % SSC was directly measured using two or three drops of juice placed on a handheld refractometer (Atago ATC-1E; Daigger & Co., Lincolnshire, Ill.). The pH of the juice of each fruit was measured, after which a 1.0-mL aliquot was diluted with 10 mL of distilled water and titrated to an endpoint of pH 8.1 using 0.0087 N NaOH; percent acidity was based on meq malic acid.

The remaining 15 fruit per treatment were used for subjective quality ratings and taste evaluations by three experienced graders. External appearance ratings were based on the degree of browning of the pericarp: 1 = (best rating) red (with green), and no darkening of outer pericarp, 2 = red with $\leq 25\%$ surface area darkened, 3 = 26% to 50% surface area darkened, 4 = 51% to 90% surface area distinctly darkened, 5 = (worst rating) 91% to 100% darkened outer pericarp. Formal grades and standards are not used for lychee in Hawaii, but an external appearance rating of 3 or higher would probably indicate reduced commercial acceptability.

Pericarp texture was evaluated as fruit were hand peeled. The scale for pericarp texture (peel) was 1 = soft and pliable, 2 = tough and leathery, and 3 = brittle. The fruit pulp was rated for its tactile and masticatory properties, and appearance, as 1 = firm, crisp and crunchy, 2 = soft, and 3 = other, which included tissue being watery or having darkened areas. The scale for taste ratings was 1 = excellent, 2 = acceptable, 3 = off flavors, 4 = highly distasteful, 5 = choose not to taste. An additional 10 fruit per treatment per replicate were held in storage at 2 and 5 °C in perforated plastic bags and fiberboard boxes and weighed at the start of the experiment and after 8 d storage to measure weight loss.

The purpose of the second experiment was to show the rate of pericarp browning under simulated commercial conditions. In the second experiment, quality determinations were performed as above before treatment and 1, 2, 5, 7, and 8 d after treatment and placement in storage at 4 °C with relative humidity at 80%, and then again 24 h later (9 d after treatment) after fruit had been held at ambient temperature (25 \pm 1 °C) in perforated plastic bags. Quality evaluations included only colorimeter measurements and subjective pericarp appearance ratings as above repeated on the same 20 fruit per treatment, on each day.

Data analysis. A two-way analysis of variance (ANOVA) procedure using the standard least squares model was performed on fruit averages to test for differences in treatment, storage temperature, and the treatment \times storage temperature interaction in the first experiment (SAS Institute, 1997). When the effect of

quarantine treatment was significant, a means separation was done using the Tukey–Kramer HSD test at $P \leq 0.05\%$. Due to limited replication ($n = 2$), data from the second experiment are presented as average trends without statistical analysis.

Results

Significant quality differences between quarantine treatments were observed in both experiments. In the first experiment, treatment effects were significant for pericarp L^{*}, C^{*}, and h[°] (Table 1) at both storage temperatures. After 8 d storage, HWI fruit were significantly darker (lower L^{*}), less intensely colored (lower C^{*}), and more yellow (higher h[°]) than IRR or untreated fruit. Also, fruit were significantly darker (lower L^{*}) (Table 1) and weight loss was significantly less with storage at 2 than 5 °C (Table 2). Treatment effects were not significant for aril L^{*}, C^{*}, and h[°] (Table 1), and there were no significant differences in % SSC, pH, or acidity due to treatment or storage temperature (Table 2). Percent weight loss was $< 6.0\%$ at 2 °C and $\leq 7.6\%$ at 5 °C storage, and was not significantly different among treatments.

After 8 d storage, fruit treated by HWI were rated as significantly less acceptable than untreated (control) fruit for pericarp texture when held at 2 °C and pericarp appearance when held at 2 or 5 °C (Table 2). Treatment effects were not significant for pulp texture or taste.

In the second experiment, pericarp darkening was more rapid for lychee fruit treated with hot-water immersion than irradiated or control fruit, and the degree of quality loss increased with increasing hot-water immersion temperature (Fig. 2). Pericarp appearance ratings for fruit treated by HWI at 49 °C were highest (the least desirable) on all days. Fruit treated by HWI at 49 °C were rated as unacceptable (ratings ≥ 3) after 1 d storage at 4 °C, whereas fruit treated by HWI at 48 °C were rated as acceptable after 5 d storage at 4 °C. IRR and untreated fruit were rated as acceptable after 8 d storage at 4 °C (Fig. 2). Pericarp L^{*}, C^{*}, and h[°] measurements showed the same trends (data not shown). For example, after 2 d the average L^{*} value for HWI fruit treated at 49 °C had dropped from an initial value of 41.4 to 32.1, whereas the L^{*} value for IRR fruit had only dropped from 41.7 to 37.3.

Discussion

The two quarantine treatments compared in our study were developed to kill Hawaii's fruit fly pests prior to export of fruit, and both treatment protocols are approved for exporting lychee. The protocol for the hot-water immersion treatment for lychee (USDA–APHIS–PPQ, 1998) contains warnings about the limited research on fruit quality after treatment application and varying tolerance among different cultivars but, until now, no quantitative information was available. For 'Kaimana' lychee, external appearance of fruit treated with hot-water immersion was rated as unacceptable after only 1 d of post-treatment storage, whereas irradiated and untreated fruit were rated as acceptable after

Table 1. Color of 'Kaimana' lychee at 8 d after treatment with hot-water immersion (HWI) or irradiation (IRR) and storage at 2 or 5 °C.

Storage temp	Treatment	Pericarp color			Flesh color		
		L*	C*	h°	L*	C*	h°
2 °C	(Initial)	38.7	34.4	34.3	49.6	2.1	161.7
	Control	36.0 a ^z	33.9 a	33.5 a	51.0	2.4	178.6
	HWI	32.0 b	22.7 b	44.0 b	54.3	3.1	168.8
	IRR	34.8 a	29.4 a	39.7 ab	53.4	2.8	164.6
5 °C	Control	37.7 a	33.1 a	35.9 a	52.5	2.6	162.2
	HWI	33.2 b	24.3 b	41.8 a	53.3	2.5	174.5
	IRR	36.5 a	31.1 a	38.4 a	51.7	2.2	177.3
<i>Main effects and interaction</i>							
Temp		*	NS	NS	NS	NS	NS
Treatment		*	*	*	NS	NS	NS
Temp × Treatment		NS	NS	NS	NS	NS	NS

^zValues are means of three replicates. Mean separation within columns and temperatures by Tukey–Kramer honestly significant difference (HSD) ($P \leq 0.05$).

NS, *Nonsignificant or significant at $P \leq 0.05$.

Table 2. 'Kaimana' lychee quality at 8 d after treatment with hot-water immersion (HWI) or irradiation (IRR) and storage at 2 or 5 °C.

Storage temp	Treatment	Wt loss (%)	Juice			Sensory			
			SSC (%)	pH	Acidity (%)	Pericarp appearance ^z	Pericarp texture ^y	Pulp ^x	Taste ^w
2 °C	(Initial)	---	20.9	4.1	0.31	1.1	1.0	1.1	1.0
	Control ^v	5.4	20.6	4.3	0.16	1.9 a	1.3 a	1.2	1.4
	HWI	5.9	20.2	4.4	0.14	3.2 b	2.2 b	1.3	1.6
	IRR	5.4	20.3	4.3	0.16	2.3 ab	1.7 ab	1.4	1.4
5 °C	Control	7.6	20.1	4.1	0.21	1.6 a	1.3 a	1.2	1.2
	HWI	7.2	20.2	4.4	0.15	3.1 b	1.8 a	1.4	1.4
	IRR	7.0	20.6	4.2	0.17	2.1 ab	1.3 a	1.4	1.2
<i>Main effects and interaction</i>									
Temp		*	NS	NS	NS	NS	NS	NS	NS
Treatment		NS	NS	NS	NS	*	*	NS	NS
Temp × Treatment		NS	NS	NS	NS	NS	NS	NS	NS

^zRatings: 1 = (best rating) red (with green) and no darkening of outer pericarp, 2 = red with $\leq 25\%$ surface area darkened, 3 = 26% to 50% surface area darkened, 4 = 51% to 90% surface area distinctly darkened, and 5 = (worst rating) 91% to 100% darkened outer pericarp.

^yScale: 1 = pliable, 2 = tough and leathery, and 3 = brittle.

^xScale: 1 = firm, 2 = soft, and 3 = other (watery, darkened areas, slimey).

^wRatings: 1 = excellent, 2 = acceptable, 3 = off flavors, 4 = highly distasteful, and 5 = choose not to taste.

^vValues are means of three replicates. Mean separation within columns and temperatures by Tukey–Kramer honestly significant difference (HSD) ($P \leq 0.05$).

NS, *Nonsignificant or significant at $P \leq 0.05$.

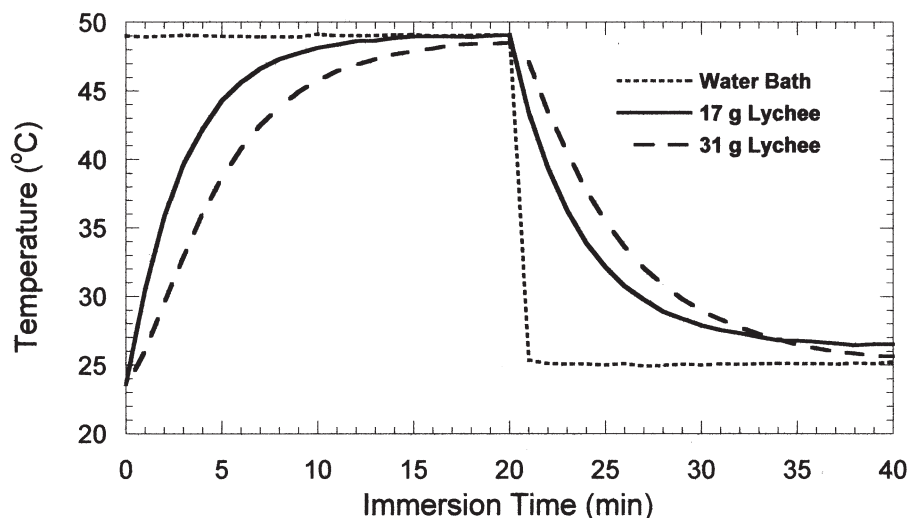


Fig. 1. Temperature profile for lychee fruit subjected to hot-water immersion at 49 °C and subsequent cooling in an ambient temperature water bath.

8 d days storage at 2–5 °C. However, taste of fruit in all treatments was acceptable after 8 d of storage. Therefore, under our conditions, hot-water immersion greatly accelerated lychee pericarp browning, and irradiation was superior to hot-water immersion as a quarantine treatment based on maintenance of fruit appearance. We previously showed that irradiation was superior to heat as a quarantine treatment for two other sapindaceous fruits, rambutan (Follett and Sanxter, 2000) and longan (Follett and Sanxter, 2002), on the basis of fruit quality maintenance.

Alternate quarantine treatments are always desirable to prevent interruption of exports in the event a treatment or treatment facility is lost. The availability of two quarantine treatments, hot-water immersion and irradiation, to control fruit flies in lychee serves this purpose in Hawaii. However, the hot-water immersion treatment for lychee may not be an acceptable alternative to irradiation due to problems with fruit quality. Quarantine cold treatments are available for export of lychee from China, Taiwan, and Israel to the United States. The duration of the cold treatment depends on the temperature and pest species to be controlled. The cold treatment for China and Taiwan is 1 °C for 15 d or 1.4 °C for 18 d to control oriental fruit fly (*Bactrocera dorsalis*) and litchi fruit borer (*Conopomorpha sinensis*), and a schedule of cold treatments between 0 and 2.2 °C for 10–16 d is approved to control Mediterranean fruit fly (*Ceratitis capitata*) in lychee exported from Israel (USDA–APHIS–PPQ, 1998). McGuire (1997) reported that cold treatment of 15 d at 1.1 °C caused minimal loss of quality in Florida lychees and compared favorably with irradiation up to 300 Gy (with 6 d storage at 5.0 °C). Hawaii should consider a lychee cold treatment as an alternative to irradiation. Cold treatments are already approved for control of Mediterranean fruit fly and oriental fruit fly in carambola and avocado exported from Hawaii to the U.S. mainland. In addition to these fruit flies, a lychee cold treatment for Hawaii would need to control two other quarantine pests, koa seedworm (*Cryptophlebia illepidia*) and litchi fruit moth (*C. ombrodela*) (Follett and Lower, 2000). Although they require more time to complete, cold treatments can be applied in transit in marine containers and refrigerated trucks. Surface transport is cost effective compared with the air transportation now used for movement of lychee from Hawaii to the U.S. mainland.

In general, lychees have a short storage life under ambient conditions. Desiccation with the accompanying loss of red color and development of browning can occur rapidly after harvest (<72 h) (Nip, 1988). Browning renders the fruit hard to sell, therefore, prolonging the shelf life could be commercially advantageous. Lowering the storage temperature is proven to extend the shelf life, and various other techniques have also been tested including packaging, fungicides, chemical treatments, and modified atmosphere with reportedly impressive results (Nip, 1988). Research is needed to identify treatments or procedures to slow the rate of quality loss in lychee after

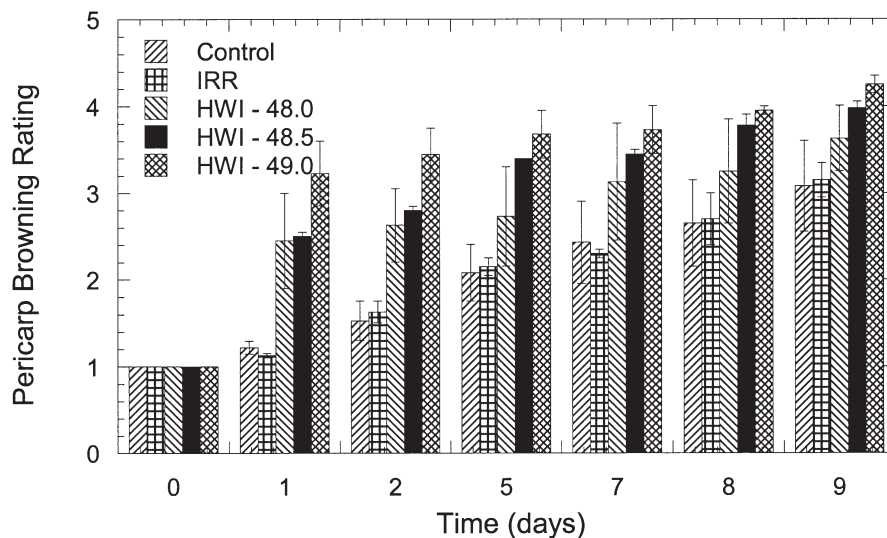


Fig. 2. Change in pericarp appearance (browning) of 'Kaimana' lychee through time after treatment with hot-water immersion (HWI) at 48, 48.5, or 49 °C, or irradiation (IRR), and storage at 4 °C.

hot-water immersion to make the use of this quarantine treatment practical. Until then, quality considerations will probably outweigh other market factors, such as the availability of treatment facilities on different islands and costs, in the choice of a quarantine treatment for Hawaii's lychee.

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